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MATERIALS AND EFFECT OF LOADING RATE(U) FOREST PRODUCTS
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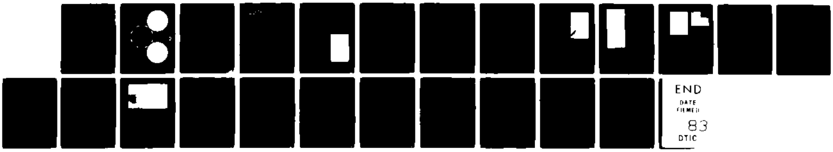

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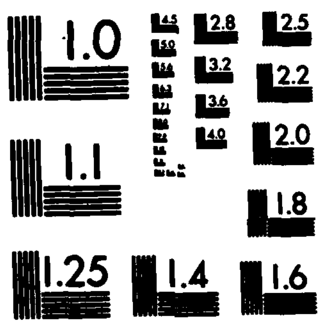

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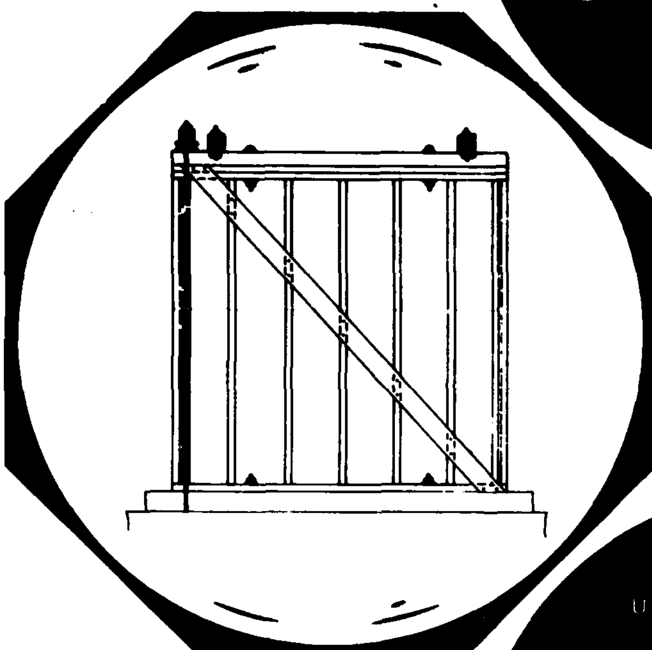
RACKING STRENGTH OF WALLS: LET-IN CORNER BRACING, SHEET MATERIALS, AND EFFECT OF LOADING RATE



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ABSTRACT

Determination of the racking strength of walls, which is a measure of a building system's ability to resist wind loads, has generally been limited to performance testing. Although a standard test method exists, deviations have often been made in speed of testing and panel configuration. The purpose of this study was to determine the relative effect of some of these deviations on test results. In addition, the racking strength of walls with let-in corner braces, which forms the basis for acceptance criteria, was evaluated.

Strength of walls with let-in corner braces, but without horizontal board sheathing, averaged less than 2/3 of the 5,200 pound value specified by FHA. Walls sheathed with fiberboard correlated well with theoretical strengths calculated using a recently developed equation. A tenfold change in rate of loading for small scale racking and lateral nail tests changed the strength 8 to 9 percent. Similar results would be expected for full size tests.

The standard and modified test procedures used will be helpful in assessing the present test procedure and the feasibility of augmenting it with small-scale racking and lateral nail resistance tests. The evaluations conducted for this study are not to be interpreted as qualification tests for any of the materials involved.

ACKNOWLEDGEMENTS

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The authors also acknowledge the contributions of William J. McCutcheon in the development of a quantitative evaluation of the racking resistance provided by the interior or field fasteners.

RACKING STRENGTH OF WALLS: LET-IN CORNER BRACING, SHEET MATERIALS, AND EFFECT OF LOADING RATE[1]

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INTRODUCTION

Walls with let-in corner bracing were once the standard of construction, and form the basis of acceptance criteria for all walls subject to shear forces. Their use diminished with the advent of more labor-efficient structural sheathing material. However, let-in bracing is again becoming more common with the increasing use of nonstructural insulation sheathing in wall construction.

Problems in the design of walls which resist shear forces fall into three categories: (1) the lack of an accepted engineering approach to predict the shear or racking strength of walls; (2) uncertainty as to the actual performance of let-in corner braces constructed in accordance with present standards; and (3) apparent inconsistencies in the interpretation of ASTM E 72 (5)[3] test procedures which result in differences in the results of racking tests conducted at various laboratories.

In addressing these related problems, the scope of this work encompasses what are essentially three independent studies. First, an analytic model is proposed to augment performance tests on various sheathing materials in walls subject to shear forces. Second, the performance of let-in corner braces constructed in accordance with present standards is evaluated. Finally, to resolve apparent inconsistencies in the interpretation of the ASTM E 72 standard, the effect on test results of deviations in testing rate is evaluated and variations in test procedures are discussed.

Both standard and modified test procedures were used in this study and the results are not intended as qualification tests for any of the materials involved.

BACKGROUND

The racking strength of a wall system is defined in terms of its ability to resist horizontal inplane shear forces. The shear, or racking, forces which act on wall systems arise primarily from wind. Although wind is fundamentally a dynamic phenomenon, recent studies (e.g., (9)) have shown that, for many conventional structures, the use of "static-equivalent"

1/ Research conducted in cooperation with the American Board-Products Association (ABPA), formerly the Acoustical and Board Products Association.

2/ Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

3/ Underlined numbers in parentheses refer to Literature Cited at end of this report.

forces in an analysis is reasonable. The current design procedure for calculating wind forces recommended by the American National Standards Institute (ANSI) (1) utilizes this concept.

In present-day light-frame construction, however, evaluation of racking strength of wall systems has generally been limited to performance testing. This technique has been employed, because there has not been an accepted engineering approach to evaluate the shear or racking strength of walls.

History of Standards

The base level of acceptance for racking performance is contained in Federal Housing Administration (FHA) Technical Circular No. 12 (8) which was developed in 1949. It was intended as an interim standard until a new permanent standard was introduced. However, none has yet been developed. A standard racking test procedure was developed by the American Society for Testing and Materials, ASTM E 72. This test is used in conjunction with the minimum load requirements specified by FHA to evaluate the racking performance of virtually every structural sheathing material in use today.

These performance requirements for structural sheathing are based on the racking strength of wood-frame walls with horizontal board sheathing and a let-in corner brace. This type of construction was common in the past but for some years fell from popularity. However, the use of let-in corner bracing is again becoming more widespread where nonstructural insulation is being used for wall sheathing. Some building codes currently accept the let-in corner brace when nonstructural sheathing is used in construction. But there have been few evaluations of wall panels with let-in corner bracing since the 1940's when the performance standard was developed. There are no well-defined requirements for lumber quality or workmanship. Also, the effect of the current nominal lumber sizes has not been investigated.

Discrepancies in Testing: Possible Causes

Recently, it has been noted (10) that there are differences in the results of racking tests conducted at various laboratories. The reasons for these discrepancies are not known, but they may result from differing interpretations of the test method.

One point that is critical to obtaining accurate racking test results is to insure that the sheathing acts independently of the test frame. When the sheathing contacts either the frame or the stop at the base of the frame, racking resistance is augmented by the compression or column effect between sheathing and frame, thus producing higher ultimate loads. Under such a condition, failure will usually occur in shearing of fasteners along the vertical joint on the center stud. This will generally be accompanied by buckling of the sheathing away from the studs. When the sheathing is properly clear of the test frame, initial failure will usually occur at the fasteners located at the tension corners of the sheet (fig. 1).

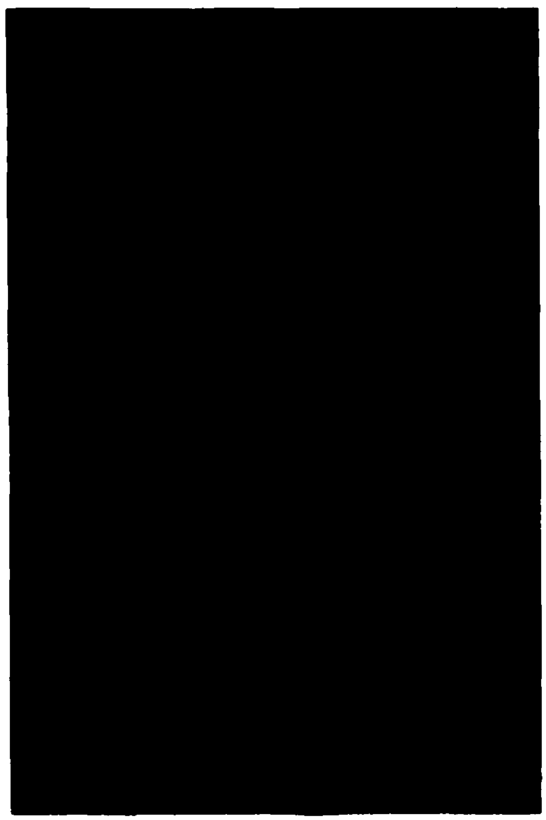


Figure 1.—Failed panel showing relative displacement and broken tension corners.
(M 143 362-10)

Sheathing which fails in this mode can generally be expected to exhibit a lower ultimate strength than sheathing which fails in a buckling mode.

It was suspected that some variation of test results might also be due to the rate of loading. Past tests were usually loaded with hand-operated hydraulic pumps. As the panel begins to yield, displacement increases at an accelerated rate. The operator must then increase this displacement rate considerably to attain higher load increments. Past work has shown that faster loading rates result in higher strength levels for wood and wood-base materials (7), but this phenomenon had not been verified on racking specimens or on lateral nail tests.

Strict interpretation of the method established in ASTM E 72 for determining the rate of loading on a test panel would require two independent test runs. The initial run must establish the displacement rate which will result in a load rate of not more than 800 pounds in 2 minutes. Subsequent testing on a given material is to be performed using this previously determined displacement rate. Because the relationship between load and deformation in racking tests is nonlinear, both load rate and displacement rate must be continuously monitored in the initial run.

DEVELOPMENT OF THEORY

At present there is no accepted engineering approach to evaluate the shear or racking strength of walls. An analytic, predictive model would be of use in the design of wall structures to augment performance tests on various types of sheathing materials. Recently the Forest Products Laboratory (FPL) developed an equation to predict the racking resistance of sheathing material mechanically fastened to a stud frame.

Equations for Sheathed Walls

The FPL equation is derived from an energy formulation whereby the externally applied load is resisted by the internal energy afforded by the fasteners. The load applied to the corners of the frame causes the frame to distort like a parallelogram while the sheathing remains rectangular (fig. 2). The diagonals of the frame and sheathing are assumed to coincide. The equation for the resistance afforded by the perimeter nails of a single sheet of sheathing is:

$$\bar{R} = \overline{sr} \sin \alpha \left[n + m - \frac{2}{3}\left(\frac{n^2 - 1}{n} \cos^2 \alpha + \frac{m^2 - 1}{m} \sin^2 \alpha \right) \right] \qquad (1)$$

where

$\bar{R}$ is racking strength of one sheet of material (pounds),

$\overline{sr}$ is lateral nail resistance at ultimate load (pounds) — i.e., a product of slip x resistance of a single fastener,

α is arctan (base of sheet divided by its height),

n is number of nail spaces on one horizontal edge, and

m is number of nail spaces on one vertical edge.

α, n, and m are further described in figure 2.

However, this relationship is complicated by the fact that most sheets also have interior or field nails. These field nails, being closer to the centroid of the sheet, offer far less resistance than the perimeter nails, but their contribution should nonetheless be considered. It is assumed that the field nails follow the distortion pattern of the perimeter nails.

Including the contribution of the field nails involves rather lengthy and cumbersome manipulation of numbers. Fortunately, most sheet products are manufactured in standard sizes, usually 4 feet wide by 8 feet high.

The terms in equation (1) were rearranged and racking coefficients, *K*, calculated for common shapes of sheathing (table 1A, appendix). The *K* coefficients reflect the panel geometry and sum the displacement vectors of all the nails for each panel configuration. The coefficients for the field nails must be mul-

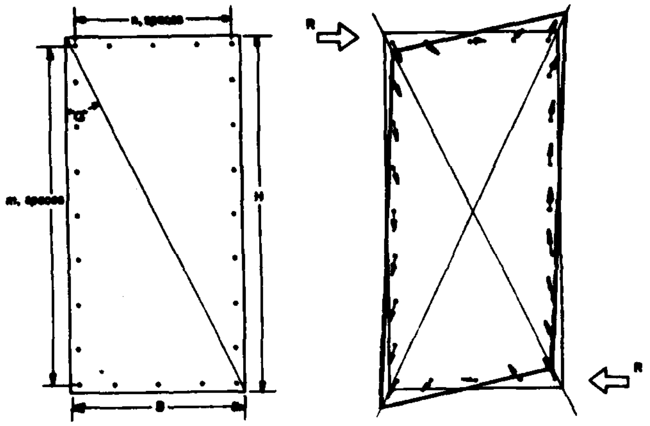


Figure 2.—Original panel shows parameters necessary to calculate racking strength. Under load, the frame distorts like a parallelogram while the sheet remains rectangular. The direction and magnitude of the nail displacements under load are shown.
(M 143 414)

tiplied by the squared ratios of the sides of the interior rectangle to the perimeter rectangle. For the most common case, where the field nails form one interior rectangle, the racking strength of *N* sheets of sheathing fastened to a stud frame can be computed by:

$$R = N \times \bar{sr}\left[(K_n + K_m)_p + (a^2K_{na} + b^2K_{nb} + a^2K_{ma} + b^2K_{mb})_f\right] + \text{FRAME} \quad (2)$$

where

R is total ultimate panel racking strength (pounds),

N is the number of sheets on the frame,

$\bar{sr}$ is lateral nail resistance at ultimate load (pounds),

K_i are racking coefficients (tabulated in the appendix),

a is ratio of vertical sides of interior to exterior rectangle,

b is ratio of horizontal sides of interior to exterior rectangle, and

FRAME is racking strength of the frame (pounds).

The subscript *p* represents the nail spaces around the perimeter and the subscript *f* identifies the nail spaces on the interior studs (field nails). The value for resistance of the frame has been taken as 450 pounds for an 8- by 8-foot frame and 250 pounds for a 2- by 2-foot frame based on regression analyses from actual tests. The terms inside the brackets must be multiplied by the number of sheets on the frame, whereas the frame value is taken only once. (See sample racking problem in appendix.)

The stud frame alone will not develop 450 pounds' resistance. Under load, the studs simply rotate at the end nail connections between studs and plates. The loaded corner does not lift to contact the tiedown nor does the stud frame rotate about its centroid. However, once the sheathing is applied there is definitely some interaction between the stud wall, sheathing, and load frame.

First, there is an increase in mass and the applied load must overcome the gravitational force. There is also some resistance in the test frame at the rollers. And finally there is some friction or rotational resistance between the lumber and sheathing that is not present in lateral nail tests. Since these factors cannot be measured directly, their contribution was taken as the load intercept from the regression equation of several independent tests.

Requisite Nail-Test Procedures

The ultimate panel racking strength as computed in the above equations is directly proportional to the lateral nail strength, and care must be taken in the choice of test method for determining this parameter. The nail-test procedure should be representative of the mode of failure in the actual joint in the racking test. There are basically two standards for lateral nail tests, ASTM D 1037 (2) and ASTM D 1761 (4).

ASTM D 1037 was designed for evaluating the properties of wood-base fiber and particle panel materials. The lateral nail test procedure described therein is adequate for fiberboard sheathing, but is not appropriate for high strength materials such as plywood or particleboard. With this method, the shank of the nail is supported by a steel yoke. It does give a true measure of the resistance of high-strength materials if the nail doesn't shear, but it is not indicative of the mode of failure in actual racking joints. With these stronger materials, the joint failure is often in the lumber rather than the sheathing, and the strength of the joint is less than the value determined by ASTM D 1037.

To better simulate the actual joint for higher strength sheathing, a modified form of the ASTM D 1761 test procedure is recommended. This test was designed for conducting lateral nail tests in wood. The modification recommended is that the cleat is a piece of sheathing material and the block is an actual piece of framing lumber taken from the panel. This assures that the actual materials from the racking tests are mated in the lateral nail tests.

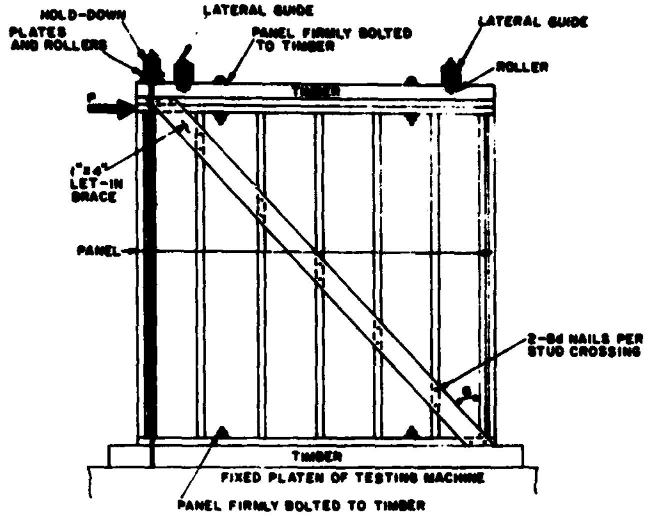
Edge distance is also important to predicting racking strength using the lateral nail test. ASTM D 1037 specifies the use of three different edge distances to determine lateral nail resistance. Although fiberboard sheathing is usually fastened with nails less than 3/4-inch from the edge of the panel, a 3/4-inch edge distance was selected because it best represents the displacement of the tension corner nails which are the critical ones. The nails along the vertical joint at the center stud are closer to the edge, but their displacement direction is essentially parallel to the edge rather than toward it. All nails on the compression half of the sheet have displacement components toward the center and are not affected by edge distance. Figure 2 shows the directions of nail displacements along with their relative magnitudes.

Effect of Let-In Corner Braces

Let-in corner braces can perform in one of two ways depending upon load direction and method of construction. These two types of braces are denoted as follows:

1. *Type I.*—Brace acts in compression as a column. A type *I* brace must be let into both the sole plate and top plates to produce adequate column action, as shown in figure 3.

2. *Type II.*—Racking strength provided solely by the lateral nail resistance in the brace. This condition exists whenever the brace is loaded in tension. A brace loaded in compression can also be of this type if installed improperly, i.e., let into the end studs rather than the top and bottom plates. This condition is shown in figure 4.



TYPE I BRACE

Figure 3.—Type *I* brace is let into the top and bottom plates and is loaded in compression. Failure is generally in a buckling mode when the brace controls ultimate strength.
(M 143 556)

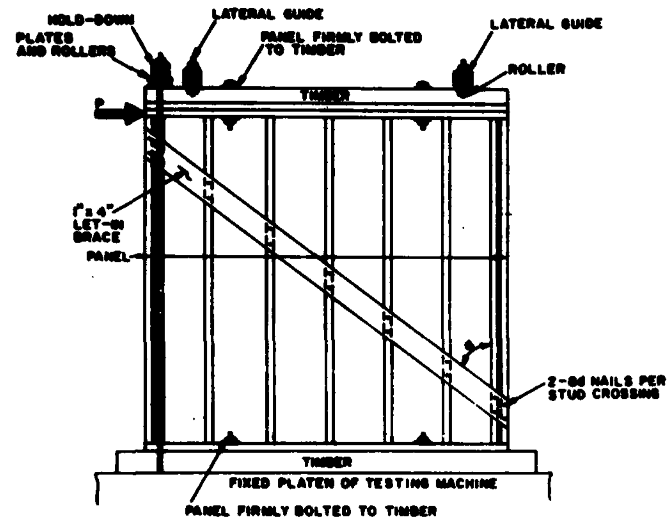
In actual practice, braces are installed with the top end toward the wall corner so that the brace toward the windward wall is acting in compression and the one toward the leeward wall is in tension.

The theories of failure for the two types of let-in corner braces are dissimilar and will be developed independently.

Type I.—Axial compressive forces are developed at each end of a type *I* brace. It is assumed that the brace performs as a slender column with inflection points at each stud crossing. When adequate frame strength is present the predominant failure mode is buckling of the brace (fig. 5). The strength of a type I brace can be calculated by tne following equation for an ideal column:

$$P_{cr} = \frac{P}{\sin \alpha} = \frac{a \pi^2 EI}{L^2} \qquad (3)$$

or



TYPE II BRACE

Figure 4.—A type *II* brace provides racking strength solely through the resistance of the fasteners. A type *I* brace loaded in tension, or a brace improperly installed (as shown), exhibits lateral nail failure.
(M 143 557)

$$P = \frac{a\pi^2 EI}{L^2} \sin\alpha \tag{4}$$

P_{cr} is critical axial force (pounds),
P is applied racking force (pounds),
α is angle between brace and vertical member,
a is end condition coefficient (use a = 1 for pinned),
E is modulus of elasticity of the brace (pounds per square inch),
I is moment of inertia of the brace ([inches]^4), and
L is unsupported clear distance between studs along the brace (inches).

Type II.—The failure observed for a type *II* brace showed that the nails at the center stud did not move during the racking test. Nail displacement was progressive toward each end of the brace. Both ends of the brace were forced axially past the end studs as illustrated in figure 6. An approximate equation for this kind of resistance is:

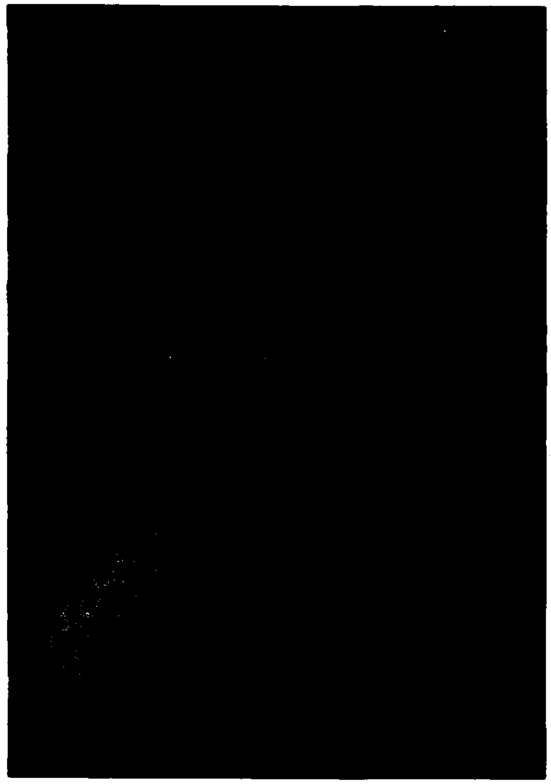


Figure 5.—Buckling failure of a type *I* compression brace.
(M 143 362-3)

$$P = Mn\bar{s}\bar{r} \sin\alpha \tag{5}$$

in which
P is applied racking load (pounds),
M is number of studs actively resisting P,
n is number of nails per stud crossing,
$\bar{s}\bar{r}$ is lateral nail resistance at ultimate load (pounds), and
α is angle between brace and vertical member.

Defining S as the total number of studs crossed by the brace (including the double studs at the ends), M is computed as:

$$M = \frac{S-1}{2} \text{ if S is odd,} \tag{6}$$

or

$$M = \frac{S}{2} \text{ if S is even.} \tag{7}$$

The ultimate racking strength of panels with let-in corner braces is sensitive to both material quality and workmanship. The

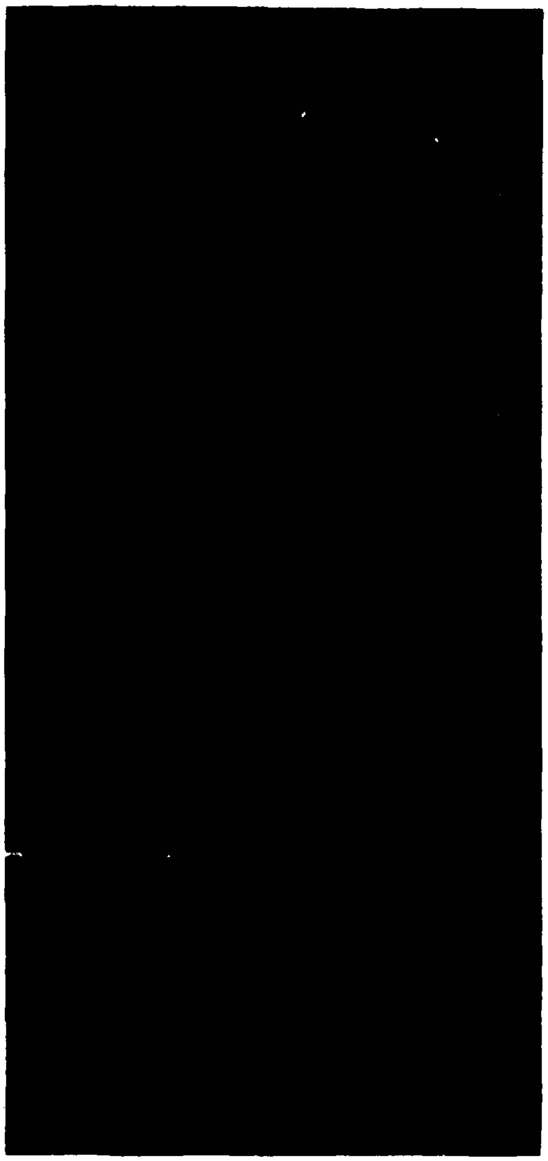


Figure 6.—Failure at the end studs of a type *II* brace where the load is carried by the lateral resistance of the nails.
(M 143 362-11)

material used in this test series was of high quality. Great care was taken to insure a near-perfect fit of the brace into the studs. A deficiency in either material quality or workmanship will reduce ultimate strengths below those predicted by the above equations.

MATERIALS

The fiberboard sheathing material and fasteners were obtained from various industrial sources. Four types of sheathing were tested (3):

1. 1/2-inch regular density,
2. 25/32-inch regular density,
3. 1/2-inch intermediate density, and
4. 1/2-inch nail base.

The approximate density ranges for the above materials are: Regular density, 18-21 pounds per cubic foot (pcf); intermediate density, 22-24 pcf, and nail base, 25-30 pcf. The 1/2-inch intermediate density fiberboard was obtained from two sources, referred to as B and C in tables 1 and 2.

Lateral nail tests were conducted on samples of sheathing removed from the racking panels following failure. At the time of testing the moisture content of the fiberboard ranged from 3.7 to 4.6 percent, and the specific gravity ranged from 0.29 to 0.42.

No. 1 Structural Light Framing is specified in ASTM E 72 for the framing lumber. An attempt was made to purchase this grade of Douglas-fir material but it was not available. Instead, No. 2 and Better was purchased and sorted to provide a clear nailing surface for application of sheathing.

Let-in corner braces were essentially clear, straight-grained material. Three species were used and specimens were chosen to obtain a wide range of moduli of elasticity. Each was identified by species and its modulus of elasticity determined with a dynamic E-computer.

Fasteners were No. 11 galvanized roofing nails. Nails used with 1/2-inch sheathing were 1-1/2 inches long, and those used with 25/32-inch sheathing were 1-3/4 inches long.

EQUIPMENT

The loading apparatus for this series of tests was far more sophisticated than previously used at FPL for racking tests. Load rates were controlled with an integrated closed-loop electrohydraulic system. The actuator controlled by this system is shown in figure 7. This system was calibrated to control

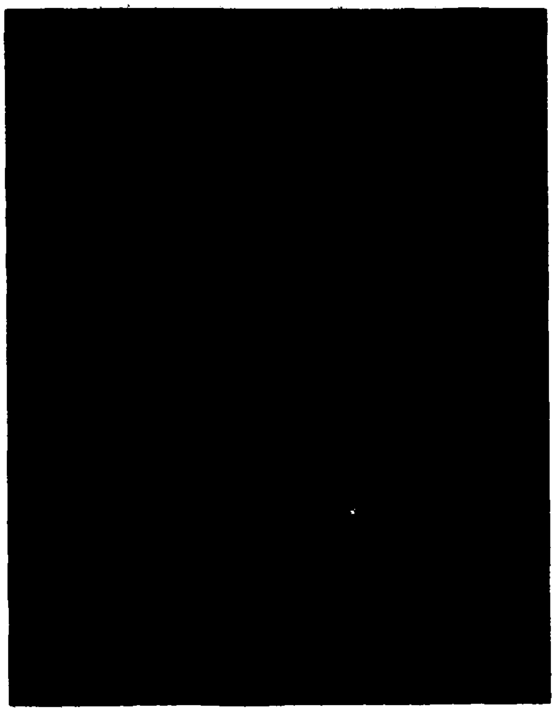


Figure 7.—Actuator controlled by an integrated closed loop electrohydraulic system.
(M 143 362-6)

Figure 8.—Overall view of the recording instruments for racking tests.
(M 143 362-5)

either the rate of force or the rate of displacement. Double bridge load cells were used — one for load control and the other for data acquisition.

Load-deflection readings were monitored continuously for the racking tests. Transducers were used to measure four distinct displacements. In addition to the three standard measurements (displacement, slip, and rotation), racking deflection was also measured as a function of the change in the diagonal length of the frame. Two x-y recorders (fig. 8), each capable of plotting two displacement readings for a given load, were used for data acquisition.

EVALUATIONS

Sheathed Panels

Large-Scale Panels

Fourteen 8- by 8-foot sheathed panels were tested in accordance with the standard racking test procedure, ASTM E 72. Two panels were initially run at a constant rate of force (400 pounds per minute). Subsequent racking tests were run at the recommended (ASTM E 72) displacement rate of 0.2 inch per minute. Details of the test frame assembly are illustrated in figure 9.

The results of the racking tests on full-sized sheathed panels are presented in table 1. Typical load versus deflection curves are shown in figure 10. Theoretical racking strengths were calculated using average lateral nail resistance values. A comparison of theoretical versus actual racking strength of panels is presented in table 2. The FPL racking equation (eq. (2)) predicts ultimate racking failure an average of 4 percent less than the observed failure load. The variability of failure loads is well within normal limits for wood-base materials.

Small-Scale Panels

Because the standard 8- by 8-foot racking tests are difficult and expensive to run, FPL designed a small-scale loading apparatus. As shown in figure 11, the apparatus consists of a pantograph frame which is pinned at the corners. The lower member can swing freely but will always remain horizontal. The two structural members and the pinned-connector straps form a parallelogram at all times.

The test specimen is inserted into the pantograph frame with the connector bars in a vertical position. Shims are inserted at two corners of the specimen to insure a snug fit, but the sheathing is always clear of the frame. The racking load is then applied directly at the corner of the bottom plate of the test specimen. The top and bottom plates are confined by the pantograph frame and remain parallel during the test.

Twenty-one 2- by 2-foot panels were tested in this frame. For 12 tests, loads were applied with a hydraulic hand pump at an approximate displacement rate of 0.2 inch per minute. Nine tests were run at various speeds to determine the influence of rate of loading on ultimate racking strength. (These nine tests are discussed later.)

For the 12-small-scale sheathed panels tested to failure using the hand pump. predicted failures averaged 4 percent below the observed values. The curve in figure 12 is a direct plot from the x-y recorder of load versus racking deflection as measured by the diagonal displacement method.

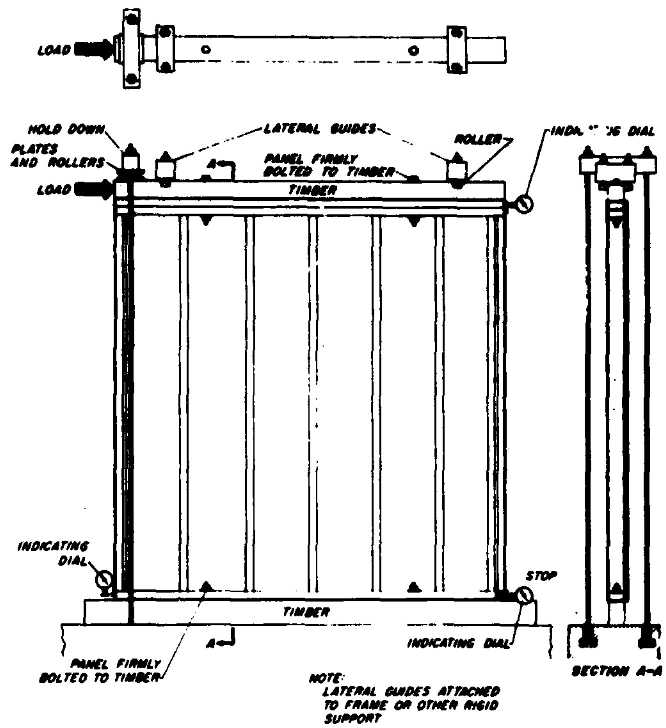


Figure 9.—Schematic diagram showing method of loading standard 8- by 8-foot racking panels and measuring deflections as depicted in ASTM Standard E 72 (three-gage method).
(M 123 922)

Measuring Panel Deflections

Comparisons of the diagonal versus the three-gage methods of recording deflections in sheathed panels, as shown in figures 10 and 13, indicate that panel stiffness as measured by the diagonal displacement method is greater than that measured by the three-gage method specified in ASTM E 72. The reason for this discrepancy is that the three-gage method incorrectly assumes that the panel rotates as a rigid body. The value taken to be panel rotation is largely local bending of the sole plate and separation of the end studs from the sole plate. Rigid body rotation is inhibited by the tiedown rods and anchor bolts. The diagonal displacement method measures the relative movement of the top and bottom plates independently of slip or rotation.

At ultimate racking failure, the displacements measured by the diagonal method average 5 percent less than those measured by the three-gage method. In earlier tests conducted without installing anchor bolts, it was found that the anchor bolts had little effect on strength but the apparent stiffness was higher. Eliminating the anchor bolts at the loaded end permits the corner to lift more. Since the uplift is subtracted from the gross deflection, the result is less net deflection. Measurements by the diagonal displacement method very nearly coincided with those from the three-gage method when anchor bolts were omitted.

The principal advantage of the diagonal displacement method is that all readings are obtained directly. Net deflections do not have to be calculated and the operator has a complete visual monitor of the entire test.

Let-In Corner Braces

The frames for the let-in corner brace tests were similar to those used in the racking tests on full-sized panels; construction details were in accordance with the ASTM E 72 standard.

Table 1.—Results of lateral nail resistance and racking tests

Material	Full scale		Small scale	
	Lateral nail resistance, $\overline{sr}$	Racking strength, P	Lateral nail resistance, $\overline{sr}$	Racking strength, P
	Lb	Lb	Lb	Lb
1/2-inch regular density	78	3,600	92	1,290 1/
	77	3,400	84	1,000
	86	3,600	92	1,000
Average	80	3,530	89	1,100
25/32-inch regular density	96	4,500	98	960
	102	4,400	86	1,060
	101	4,500	104	1,000
Average	100	4,470	96	1,010
1/2-inch intermediate density (Source C)	112	4,050	117	1,320
	125	4,850	138	1,320
	120	3,900	125	1,320
Average	119	4,270	127	1,320
1/2-inch intermediate density (Source B)	88	3,700	—	—
	90	3,400	—	—
Average	89	3,550		
1/2-inch nail base	186	6,450	187	1,880
	177	6,000	194	1,920
	191	6,700	192	1,710
Average	185	6,380	191	1,840

1/ Test was conducted immediately prior to discovery of equipment malfunction on next panel.

Six type *I* braces and one type *II* brace of clear, straight-grained nominal 1- by 4-inch material were carefully fitted into the 8- by 8-foot frames and tested as specified in ASTM E 72. Results of these tests are given in table 3. Equation (4) is applicable only to those three cases where the brace failed in buckling. For these three, predicted failure loads averaged 6 percent less than the recorded test-failure loads. In the other cases, the stud frame failed before the full capacity of the brace was reached. For braces with high stiffness, the stud frame appears to limit maximum load. Figure 13 illustrates typical load versus deformation curves for a type *I* brace.

Failure in the single type *II* brace tested was not as well defined. Panel stiffness was lower than for the type *I* braces. The maximum

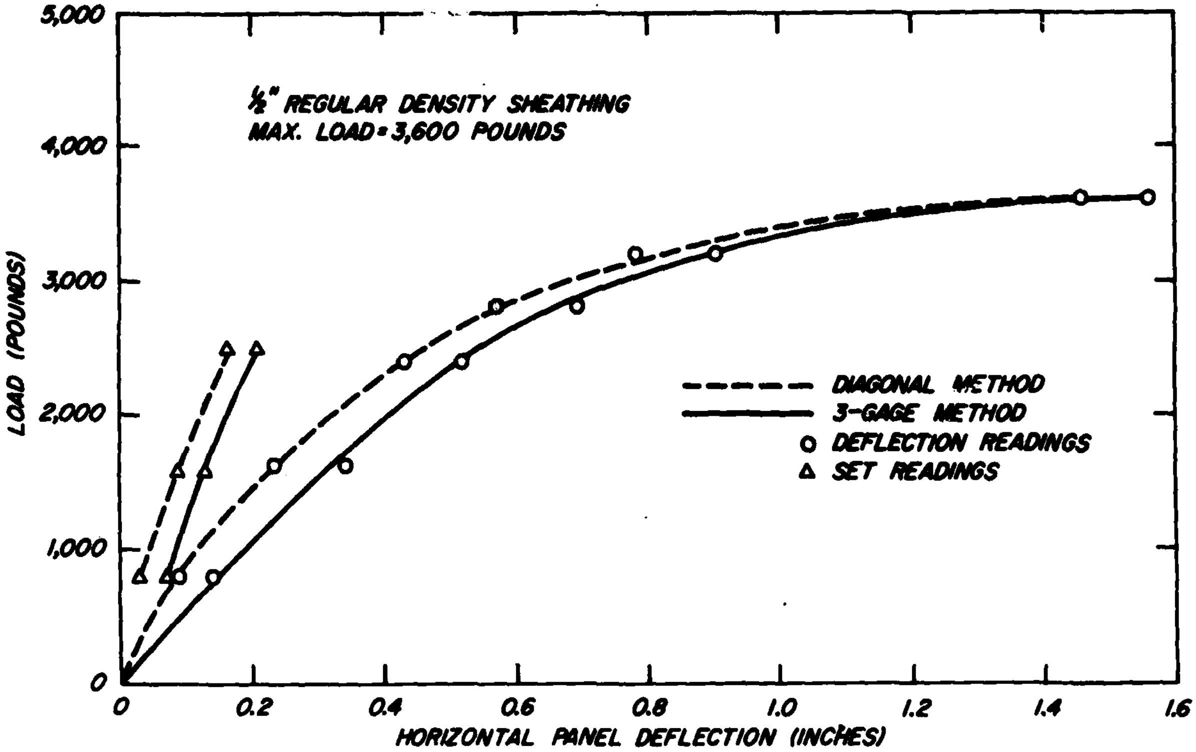


Figure 10.—Typical load-deflection curves for 8- by 8-foot panel sheathed with fiberboard by the three-gage method and diagonal displacement method.
(M 144 372)

racking load of 1,900 pounds is 19 percent higher than predicted by equation (6).

Unpublished previous tests in which horizontal board sheathing was used in conjunction with let-in bracing indicated that the FHA minimum required racking load of 5,200 pounds is attainable. When horizontal board sheathing is installed on the same side as the brace, the brace is supported full length against outward buckling. One frame tested in this way failed at 6,050 pounds. Board sheathing applied on the side opposite to the brace reinforces the stud frame and permits the brace to reach its ultimate buckling load. However, the brace is not restrained against buckling, and one frame tested in this way failed at 5,450 pounds.

Lateral Nail Tests

Lateral nail resistance values were determined using the ASTM D 1037 procedure for all four fiberboard sheathing materials. Nails were from the same shipment as those used in the racking panels. The effects of testing at various edge distances were also evaluated.

Results of the lateral nail tests are given in table 1. The effect of variation of edge distance on lateral nail resistance is shown in figure 14. The ultimate nail load increases with edge distance in a nonlinear manner. As expected, the curve approaches an asymptotic maximum load at which the nail shank acts in direct bearing on the sheathing independently of edge distance. An edge distance of 3/4-inch in the lateral nail test corresponds to the edge distance (in the direction of nail movement) of the corner nails in a test panel.

Rate of Loading

Nine small-scale racking tests and nine lateral nail tests were conducted at different displacement rates to evaluate how the rate of

Table 2.—Theoretical vs. actual racking strength

Material	Full Scale 1/			Small Scale 2/		
	Theoretical racking strength R	Average actual racking strength P	Ratio R/P	Theoretical racking strength R	Average actual racking strength P	Ratio R/P
	Lb	Lb		Lb	Lb	
1/2-inch regular density	3,130	3,530	0.89	970	1,100	0.88
25/32-inch regular density	3,800	4,470	.85	1,030	1,010	1.02
1/2-inch inter-mediate density (Source C)	4,430	4,270	1.04	1,280	1,320	.97
1/2-inch inter-mediate density (Source B)	3,430	3,550	.97	—	—	—
1/2-inch nail base	6,640	6,380	1.04	1,790	1,840	.97
Average			.96			.96

1/ Full-scale tests consisted of two 4 x 8 ft sheets with 11-gage roofing nails spaced 3 in. (perimeter) and 6 in. (field) on centers, $R = 33.48\overline{sr} + 450$.

2/ Small-scale tests consisted of two 1 x 2 ft sheets with 11-gage roofing nails spaced 3 in. (perimeter) and 6 in. (field) on centers, $R = 8.06\overline{sr} + 250$.

loading affects strength.

Load rates were selected to correlate racking panel speed with lateral nail speed. The equation relating the respective vector displacements of a corner nail to the test panel takes the form:

$$\Delta = \frac{2\delta}{\sin\alpha} \qquad (8)$$

in which

Δ is panel displacement rate (inches per minute),

δ is corner nail displacement rate (inches per minute), and

α is arctan (base of sheet divided by its height).

For the panels tested, this relation becomes:

$$\delta = 0.224\,\Delta \qquad (9)$$

The ratio of speeds only approximated the above equation due to a discrete rather than continuous speed control on the testing machines.

Loading rate affects both ultimate nail load and apparent panel strength. Past work on rate of loading of wood-base materials has correlated the load rate with strength properties. In work of this type, the time scale (typically expressed as the time-to-failure) is logarithmic and the strength scale linear.

Figure 11.—Pantograph frame designed for testing small-scale racking specimens.
(M 141 775-4)

Table 3.—Results of racking tests on 8- by 8-foot panels with let-in braces loaded in compression

Panel number	Modulus of elasticity — brace[1]	Theoretical racking strength, [2] R	Actual racking strength, P	Ratio R/P
	Million Lb/in.^{2}	Lb	Lb	
1	1.20	2,490	2,900	0.86
2	2.56	N/A (5,310)	4,450	—
3	1.77	3,670	3,550	1.03
4	1.07	2,220	2,350	.94
5	1.59	N/A (3,300)	2,850	—
6	1.84	N/A (3,820)	3,000	—
Average ratio				.94

1/ All let-in braces were nominal 1 x 4 in. boards of the following species: White pine, Panel 1; southern pine, Panels 2 and 3; sugar pine, Panels 4 through 6. Moduli of elasticity were determined by a transverse vibration technique (E-computer).

2/ Theory is only applicable to those panels in which the brace buckled. In Panels 2, 5, and 6, the frame failed before the full brace capacity was attained. Theoretical strengths are shown in brackets.

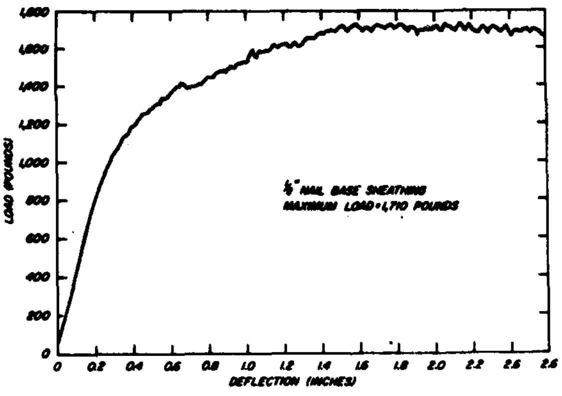


Figure 12.—Typical load-deflection curve for a small-scale racking panel as plotted directly by an x-y recorder. The fluctuations above the proportional limit show slippage in the fasteners as force is increased by hand pump.
(M 144-371)

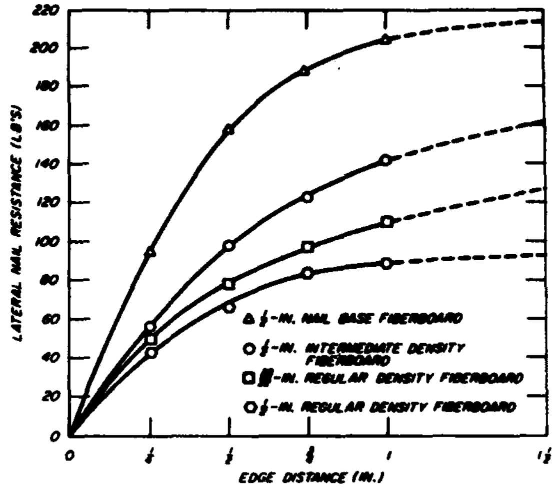


Figure 14.—Lateral nail resistance at various edge distances for four types of fiberboard sheathing.
(M 144 300)

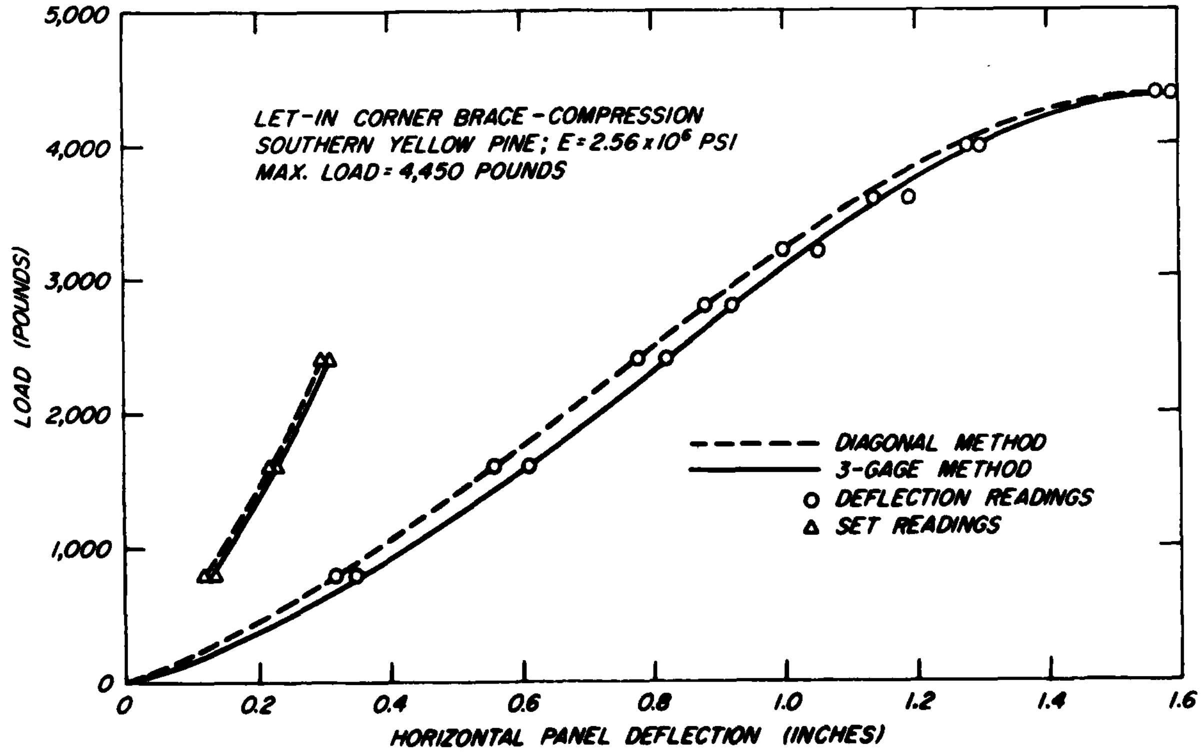


Figure 13.—Typical load-deflection curve for 8- by 8-foot panel with let-in corner brace loaded in compression. (Type I brace)
(M 144 369)

Results of both the small-scale racking and lateral nail tests conducted at different loading rates are presented in table 4. Although the sample size was far too small to develop meaningful confidence levels, the trends are apparent. The results of this limited study agree with past work on strength properties of wood and wood-base materials (7,8). Regression analyses indicate that a tenfold increase in time-to-failure (inverse of speed) will reduce apparent strength by 8 to 9 percent. For the 2- by 2-foot panels sheathed with 1/2-inch intermediate density fiberboard, the relationship between rate of loading and ultimate racking load can be expressed as follows:

$$R = 1{,}370(1 - 0.09 \log_{10} T) \qquad (10)$$

in which

R is racking load at failure (pounds), and

T is time to failure (minutes) computed as the displacement at failure divided by test speed. Displacement at failure for these tests averaged 2 inches.

The relationship for ultimate lateral nail load is:

$$\overline{sr} = 110(1 - 0.08 \log_{10} T) \qquad (11)$$

in which

$\overline{sr}$ is lateral nail resistance at ultimate load (pounds), and

T is time to failure (minutes).

Displacement at failure for these tests averaged 0.4 inches.

Table 4—Effect of rate of loading on maximum strength values of nails and 2- by 2-foot panels

Panel number	Lateral nail		Small scale racking	
	Test speed	Maximum load	Test speed	Maximum load
	In/min	Lb	In./min	Lb
1b	0.02	102	0.1	1,090
2b	.02	104	.1	1,370
3b	.02	106	.1	1,220
Average		104		1,230
4b	.50	116	2	1,440
5b	.50	105	2	1,190
6b	.50	108	2	1,265
Average		110		1,300
7b	1.0	114	5	1,510
8b	1.0	132	5	1,480
9b	1.0	131	5	1,410
Average		126		1,470

CONCLUSIONS

Theoretical and actual racking strength of panels sheathed with fiberboard were closely correlated. Also the dispersion or variability in the data was within normal limits expected for wood-base material. The equations for computing racking strength are independent of panel size, so both simple lateral nail tests and small-scale racking tests could augment the more expensive full-size panel tests.

The actual performance of let-in corner braces, without the horizontal board sheathing, is well below the 5,200-pound level cited in the Federal Housing Administration Technical Circular No. 12. [illegible]. Although the strength and stiffness of the brace are important, a level is reached where the stud frame controls ultimate strength.

The rate of loading does affect ultimate load for both lateral nail and racking tests. Results of this study, which indicated an 8 to 9 percent increase in strength with a tenfold increase in speed, agree with past studies on the effect of loading rate on strength of wood and wood-base materials. This magnitude is probably not significant enough to justify expensive and sophisticated electronic control systems. A careful operator, using a hand-operated hydraulic pump, should be able to obtain reliable results. The recommended displacement rate of 0.2 inch per minute, if applied to all sheathing materials, would help to clarify ASTM Standard E 72. Ultimate racking strength appears to be more sensitive to contact between test frame and sheathing than to minor variations in the rate of loading.

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APPENDIX

Sample Racking Problem

Determine the racking strength for the following panel: two 4- by 8-foot sheets of 1/2-inch regular density fiberboard are nailed to a standard 8-foot-long stud wall with studs on 16-inch centers. The nail spacing is 3 inches around the perimeter and 6 inches for field nails. The nail strength, $\overline{sr}$, is 85 pounds as determined from lateral nail tests.

Panel Geometry—the width to height ratio for the sheet,

B/H - 0.5 (the right side of table 1A applies)

Nail Spaces—(see fig. 1A)

Perimeter: m_p = 96/3 = 32

n_p = 48/3 = 16

Field : m_f = 84/6 = 14

n_f = 16/16 = 1

Ratios of Interior to Exterior Rectangles

Vertical side, $a = H_f/H_p$ = 84/96

Horizontal size, $b = B_f/B_p$ = 16/48

Theoretical racking strength, R (eq. (2)) is

$$R = N\overline{sr}\left[(K_n + K_m)_p + (a^2K_{na} + b^2K_{nb} + a^2K_{ma} + b^2K_{mb})_f\right] + \text{FRAME}$$

from table 1A:

For	$n_p = 16$	K_n		= 3.35
	$m_p = 32$	K_m		= 12.40
	$n_f = 1$	a^2K_{na}	$= (84/96)^2 \times 0.09$	= 0.07
		b^2K_{nb}	$= (16/48)^2 \times 0.36$	= 0.04
	$m_f = 14$	a^2K_{ma}	$= (84/96)^2 \times 0.42$	= 0.32
		b^2K_{mb}	$= (16/48)^2 \times 5.01$	= 0.56
	Total coefficient per sheet			= 16.74

N = 2 sheets, $\overline{sr}$ = 85 pounds, and FRAME = 450 pounds

Estimated racking strength: R = 2 x 85 x 16.74 + 450 = 3,300 pounds

Table 1A.—Racking coefficents for various panel shapes and number of fasteners

Nail spaces n or m	Sheet width/height (B/H) 0.25						0.50					
	K_{na}	K_{nb}	K_n	K_{ma}	K_{mb}	K_m	K_{na}	K_{nb}	K_n	K_{ma}	K_{mb}	K_m
1	0.01	0.23	0.24	0.01	0.23	0.24	0.09	0.36	0.45	0.09	0.36	0.45
2	.03	.23	.26	.01	.46	.47	.18	.36	.54	.09	.72	.80
3	.04	.28	.32	.02	.68	.70	.27	.44	.71	.11	1.07	1.18
4	.06	.34	.40	.02	.91	.93	.36	.54	.89	.13	1.43	1.57
5	.07	.41	.48	.03	1.14	1.17	.45	.64	1.09	.16	1.79	1.95
6	.09	.48	.57	.03	1.37	1.40	.54	.76	1.29	.19	2.15	2.34
7	.10	.55	.65	.03	1.60	1.63	.63	.87	1.49	.22	2.50	2.72
8	.11	.63	.74	.04	1.83	1.87	.72	.98	1.70	.25	2.86	3.11
9	.13	.70	.83	.04	2.05	2.10	.80	1.10	1.90	.27	3.22	3.49
10	.14	.78	.92	.05	2.28	2.33	.89	1.22	2.11	.30	3.58	3.88
11	.16	.85	1.01	.05	2.51	2.56	.98	1.33	2.32	.33	3.94	4.27
12	.17	.93	1.10	.06	2.74	2.80	1.07	1.45	2.52	.36	4.29	4.66
13	.19	1.00	1.19	.06	2.97	3.03	1.16	1.57	2.73	.39	4.65	5.04
14	.20	1.08	1.28	.07	3.20	3.26	1.25	1.69	2.94	.42	5.01	5.43
15	.21	1.15	1.37	.07	3.42	3.50	1.34	1.80	3.15	.45	5.37	5.82
16	.23	1.23	1.46	.08	3.65	3.73	1.43	1.92	3.35	.48	5.72	6.21
17	.24	1.30	1.55	.08	3.88	3.96	1.52	2.04	3.56	.51	6.08	6.59
18	.26	1.38	1.63	.09	4.11	4.19	1.61	2.16	3.77	.54	6.44	6.98
19	.27	1.45	1.72	.09	4.34	4.43	1.70	2.28	3.98	.57	6.80	7.37
20	.29	1.53	1.81	.10	4.57	4.66	1.79	2.40	4.19	.60	7.16	7.75
21	.30	1.61	1.90	.10	4.79	4.89	1.88	2.52	4.39	.63	7.51	8.14
22	.31	1.68	1.99	.11	5.02	5.13	1.97	2.63	4.60	.66	7.87	8.53
23	.33	1.76	2.08	.11	5.25	5.36	2.06	2.75	4.81	.69	8.23	8.92
24	.34	1.83	2.17	.11	5.48	5.59	2.15	2.87	5.02	.72	8.59	9.30
25	.36	1.91	2.26	.12	5.71	5.83	2.24	2.99	5.23	.75	8.94	9.69
26	.37	1.98	2.36	.12	5.93	6.06	2.33	3.11	5.44	.78	9.30	10.08
27	.39	2.06	2.45	.13	6.16	6.29	2.41	3.23	5.64	.81	9.66	10.47
28	.40	2.14	2.54	.13	6.39	6.53	2.50	3.35	5.85	.84	10.02	10.85
29	.41	2.21	2.63	.14	6.62	6.76	2.59	3.47	6.06	.87	10.38	11.24
30	.43	2.29	2.72	.14	6.85	6.99	2.68	3.59	6.27	.90	10.73	11.63
31	.44	2.36	2.81	.15	7.08	7.22	2.77	3.70	6.48	.93	11.09	12.02
32	.46	2.44	2.90	.15	7.30	7.46	2.86	3.82	6.69	.96	11.45	12.40
33	.47	2.52	2.99	.16	7.53	7.69	2.95	3.94	6.89	.99	11.81	12.79
34	.49	2.59	3.08	.16	7.76	7.92	3.04	4.06	7.10	1.02	12.16	13.18
35	.50	2.67	3.17	.17	7.99	8.16	3.13	4.18	7.31	1.05	12.52	13.57

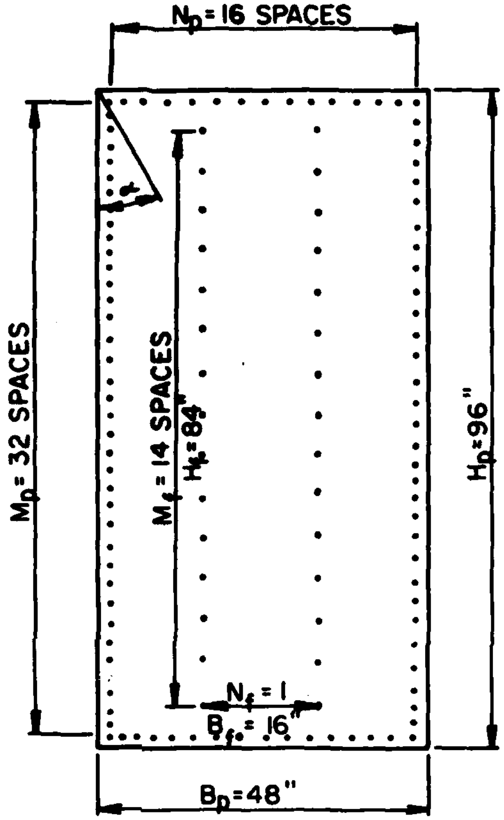

Figure 1A.—Sheet size and nail spacing for sample racking problem.
(M 144 318)

U.S. Forest Products Laboratory.

Racking strength of walls: Let-in corner bracing, sheet materials, and effect of loading rate, by Roger L. Tuomi and David S. Gromala, Madison, Wis., FPL, 1977.

21 p. (USDA Forest Serv. Res. Pap. FPL 301).

Investigates reliability of current racking tests for walls. Also evaluates walls with let-in corner braces.

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